USER MANUAL

HEX

Force Torque Sensor

For the KUKA KRC4

Edition E9

OnRobot FT KUKA Software Version 4.0.0

September 2018

Content

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The original language for this publication is English. Any other languages that are supplied have been translated from English.

1 Preface

1.1 Target Audience

This document is intended for integrators who design and install complete robot applications. Personnel working with the sensor are expected to have the following expertise:

- Basic knowledge of mechanical systems
- Basic knowledge of electronic and electrical systems
- Basic knowledge of the robot system

1.2 Intended Use

The sensor is designed for measuring forces and torques, installed on the end effector of a robot. The sensor can be used within the specified measurement range. Using the sensor outside of its range is considered misuse. OnRobot is not liable for any damage or injury resulting from misuse.

1.3 Important safety notice

The sensor is *partly completed machinery* and a risk assessment is required for each application the sensor is a part of. It is important that all safety instructions herein are followed. The safety instructions are limited to the sensor only and do not cover the safety precautions of a complete application.

The complete application must be designed and installed, in accordance with the safety requirements specified in the standards and regulations of the country where the application is installed.

1.4 Warning Symbols

DANGER:

This indicates a very dangerous situation which, if not avoided, could result in injury or death.

WARNING:

This indicates a potentially hazardous electrical situation which, if not avoided, could result in injury or damage to the equipment.

WARNING:

This indicates a potentially hazardous situation which, if not avoided, could result in injury or major damage to the equipment.

CAUTION:

This indicates a situation which, if not avoided, could result in damage to the equipment.

NOTE:

This indicates additional information such as tips or recommendations.

1.5 Typographic Conventions

The following typographic conventions are used in this document.

Table 1: Conventions

`Courier Text`	File paths and file names, code, user input and computer output.
Italicized text	Citations and marking image callouts in text.
Bold text	UI elements, including text appearing on buttons and menu options.
Bold, blue text	External links, or internal cross-references.
<angle brackets>	Variable names that must be substituted by real values or strings.
1. Numbered lists	Steps of a procedure.
A. Alphabetical lists	Image callout descriptions.

2 Getting Started

2.1 Scope of Delivery

In the KUKA KRC4 OnRobot HEX Sensor Kit everything is provided that is required to connect the OnRobot force/torque sensor to your KUKA robot.

- OnRobot 6-axis force/torque sensor (variant HEX-E or HEX-H)
- OnRobot Compute Box
- OnRobot USB Drive
- Adapter-A2, B2, or C2
- sensor cable (4 pin M8 - 4 pin M8, 5 m)
- Compute Box power cable (3 pin M8 – open ended)
- Compute Box power supply
- UTP cable (RJ45 - RJ45)
- PG16 cable gland
- plastic bag, containing:
    - cable holder, with integrated screw
    - M6x8 screws (10)
    - M5x8 screws (9)
    - M4x6 screws (7)
    - M6 washer (10)
    - M5 washer (9)

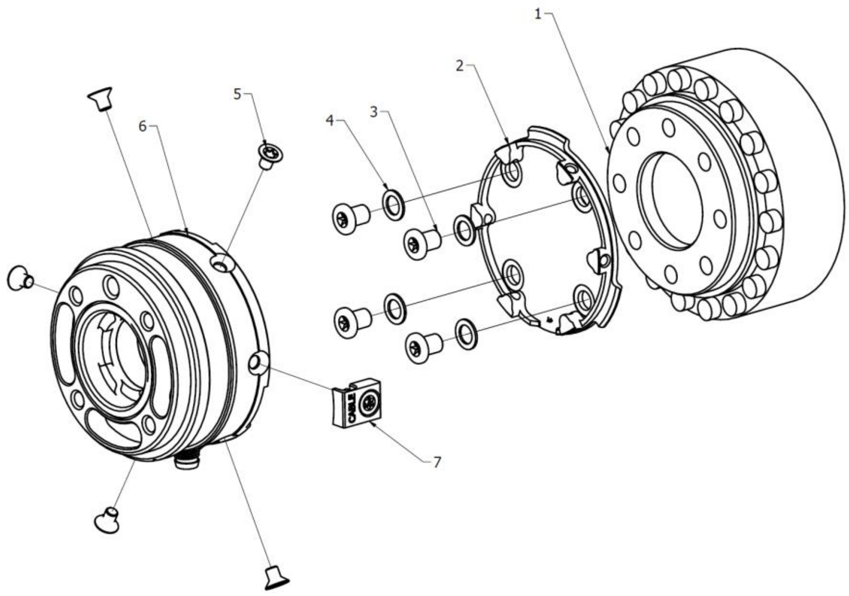
2.2 Mounting

Use only the screws provided with the sensor. Longer screws could damage the sensor or the robot.

2.2.1 ISO 9409-1-50-4-M6 Tool Flange

To mount the sensor to *ISO 9409-1-50-4-M6* tool flange, follow this process:

1. Fasten Adapter-A2 to the robot by four M6x8 screws. Use 6 Nm tightening torque.
2. Fasten the Sensor to the adapter by five M4x6 screws. Use 1,5 Nm tightening torque.
3. Fasten the cable to the Sensor with the Cable Holder by the M4x12 screw. Use 1,5 Nm tightening torque.



Legend: 1 – robot tool flange, 2 – Adapter-A2, 3 - M6x8 screws, 4 – M6 washers, 5 – M4x6 screws, 6– sensor, 7 – cable holder

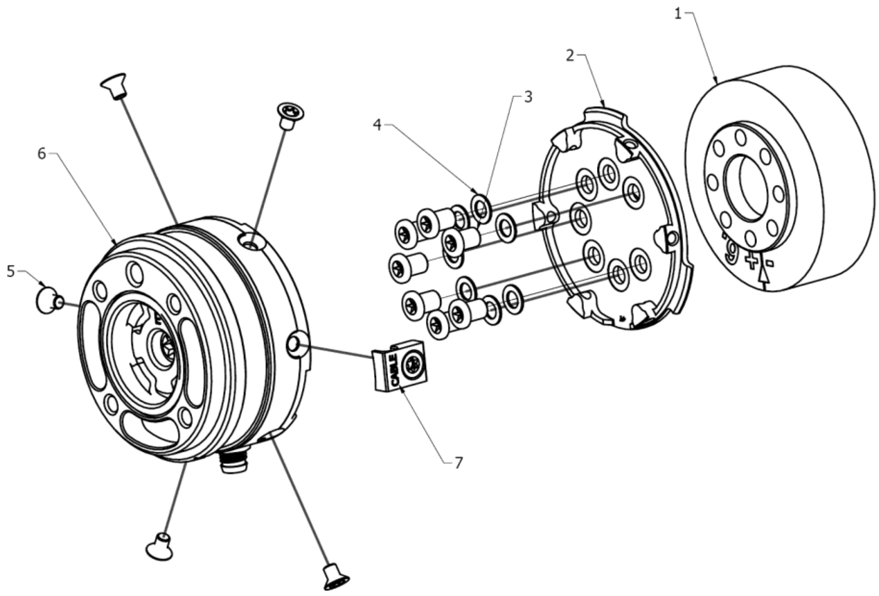
2.2.2 ISO 9409-1-31.5-7-M5 Tool Flange

To mount the sensor to *ISO 9409-1-31.5-7-M5* tool flange, follow this process:

Fasten Adapter-B2 to the Robot by seven M5x8 Screws. Use 4 Nm tightening torque.

Fasten the Sensor to the adapter by five M4x6 screws. Use 1,5 Nm tightening torque.

Fasten the cable to the Sensor with the Cable Holder by the M4x12. Use 1,5 Nm tightening torque.



Legend: 1 – robot tool flange, 2 – Adapter-B2, 3 – M5x8 screws, 4 – M5 washers, 5 – M4x6 screws, 6 – sensor, 7 – cable holder

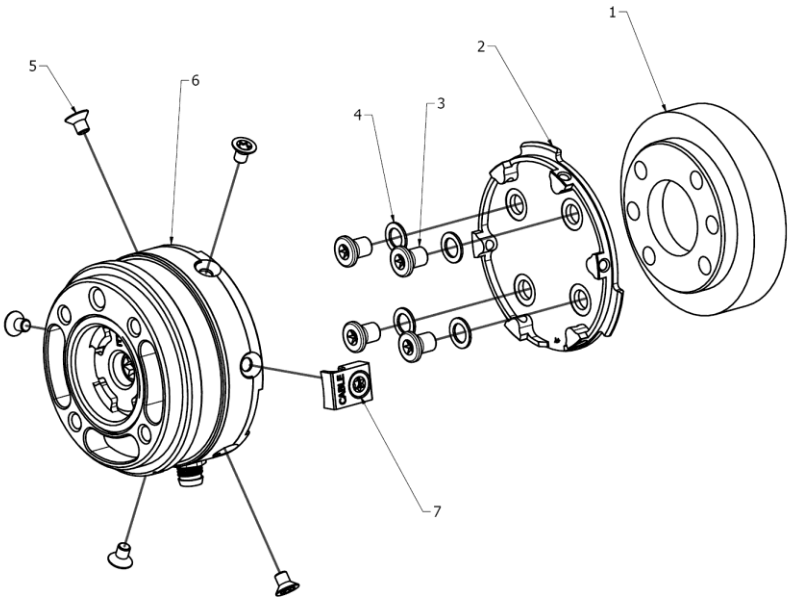
2.2.3 ISO 9409-1-40-4-M6 Tool Flange

To mount the sensor to *ISO 9409-1-40-4-M6* tool flange, follow this process:

1. Fasten Adapter-C2 to the Robot by four M6x8 Screws. Use 6 Nm tightening torque.

   Fasten the Sensor to the adapter by five M4x6 screws. Use 1,5 Nm tightening torque.

   Fasten the cable to the Sensor with the Cable Holder by the M4x12 screw. Use 1,5 Nm tightening torque.



Legend: 1 – robot tool flange, 2 – Adapter-C2, 3 - M6x8 screws, 4 – M6 washers, 5 – M4x6 screws, 6– sensor, 7 – cable holder

2.3 Cable Connections

To connect the sensor, follow this process:

1. Connect the 4 pin M8 cable (5m long) to the sensor and secure it to the robot with cable ties.

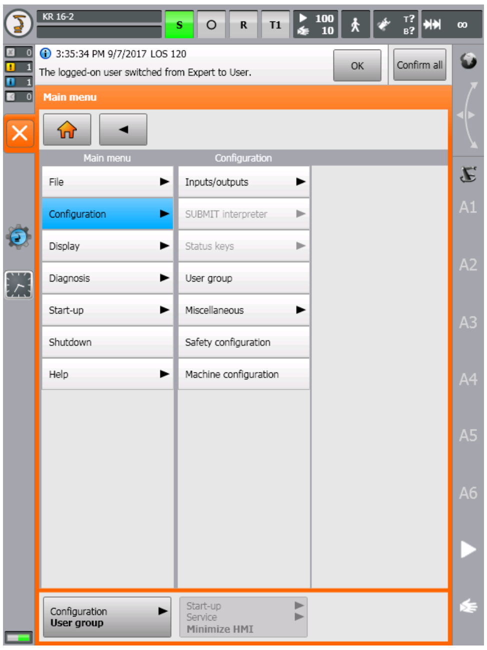
   > Make sure that enough extra cable length is available around the joints for bending.

2. Place the converter somewhere near the KUKA robot control cabinet and connect the 4 pin M8 sensor cable.
3. Connect the Compute Box's Ethernet interface with the KUKA controller's Ethernet interface (KLI) via the supplied UTP cable (yellow).
4. Use the Compute Box power supply to power the Compute Box, and the sensor from a wall socket.
5. Apply the correct network settings to both the Ethernet converter and the KUKA robot. The default Ethernet converter IP address is 192.168.1.1. If you need to change the IP address of the sensor, see **Changing the IP of the Sensor**.

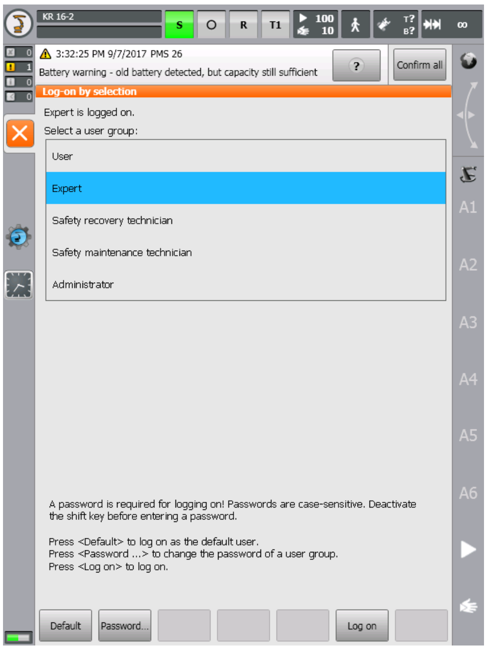
2.4 Software Installation

2.4.1 KUKA Line Interface Setup (Ethernet)

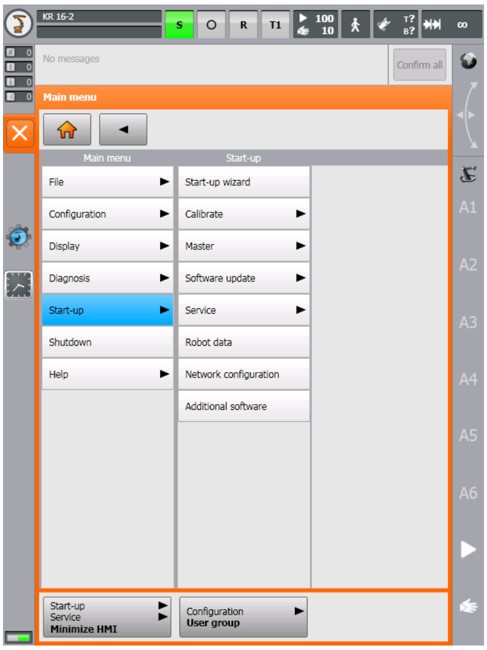
To change the IP settings of the KUKA robot controller, follow this process:



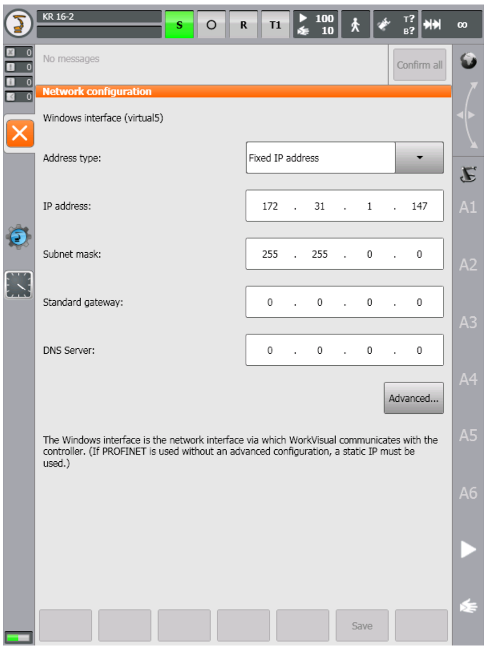
1. Go to ‘Configuration’ > ‘User group’



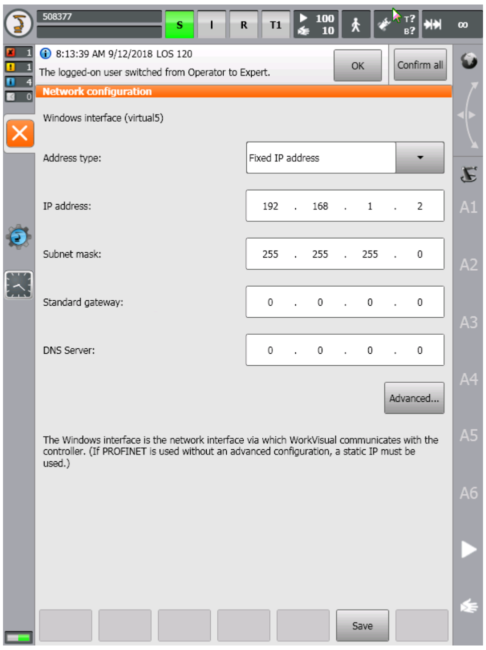
2. Select ‘Expert’ and type in your password



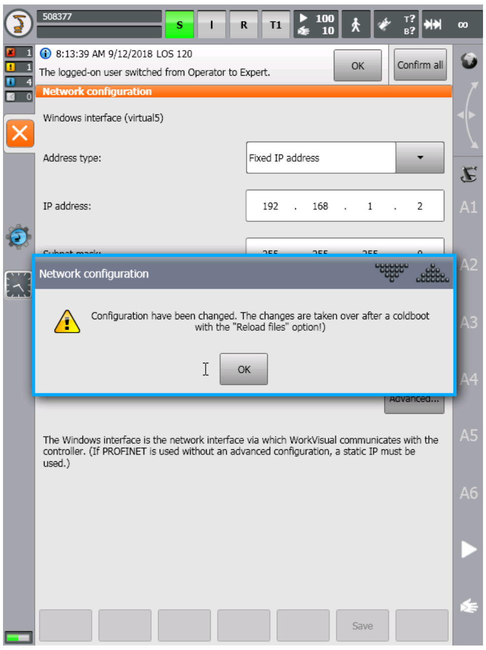
3. Go to ‘Start-up’ > ‘Network configuration’



4. Set the IP address to be on the same subnet as the Compute Box

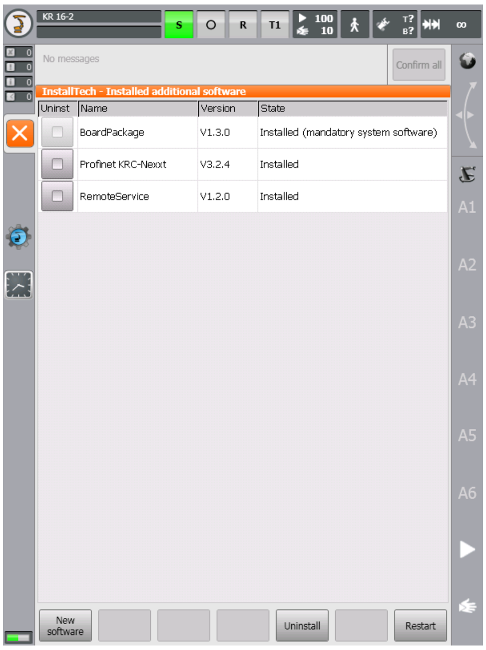


5. Click save

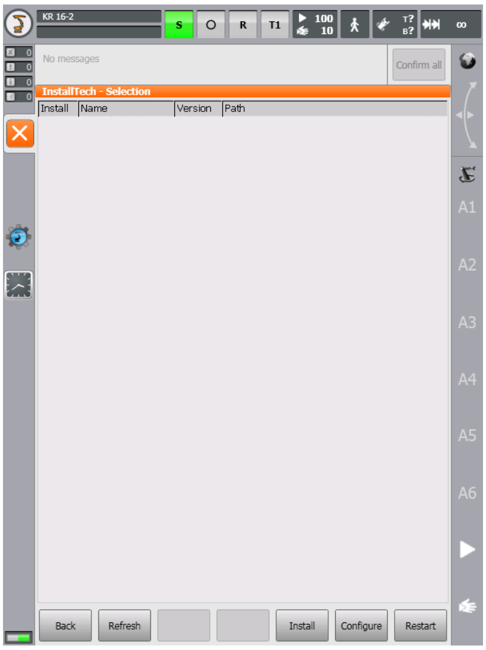


6. Accept the prompts and restart the robot controller

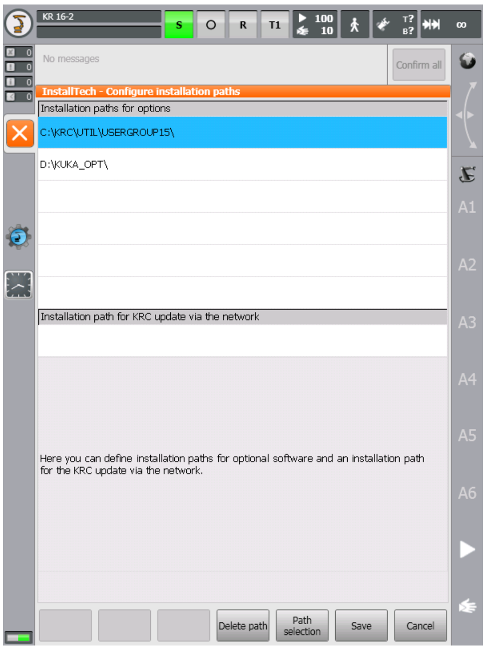
2.4.2 KUKA Robot Sensor Interface Package Installation



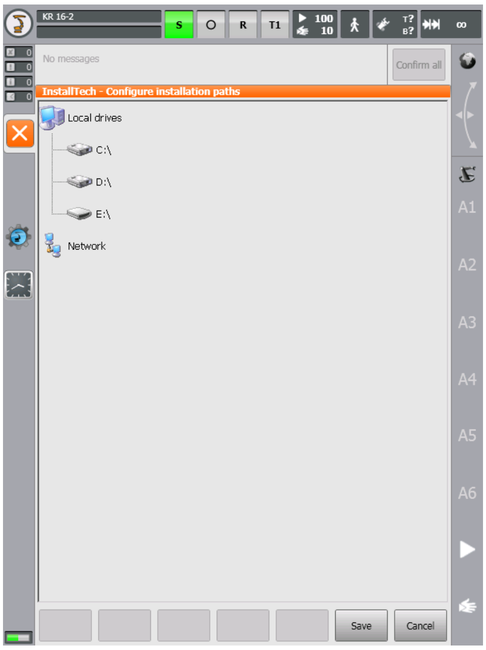
1. Go to 'Start-up' > 'Additional software', click on 'New software'



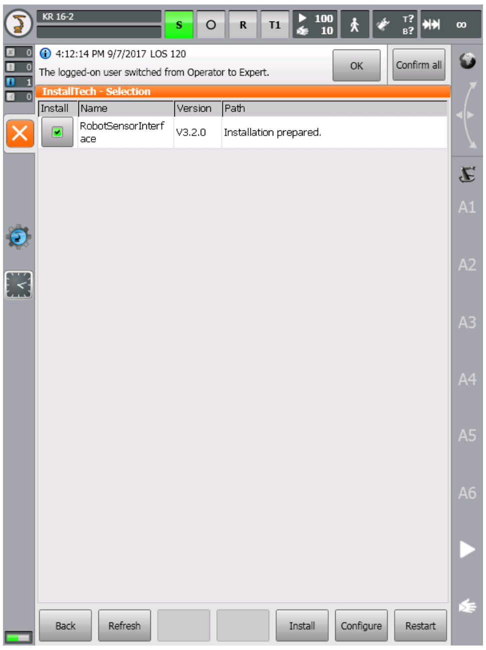
2. If no packages are listed click on 'Configure'.



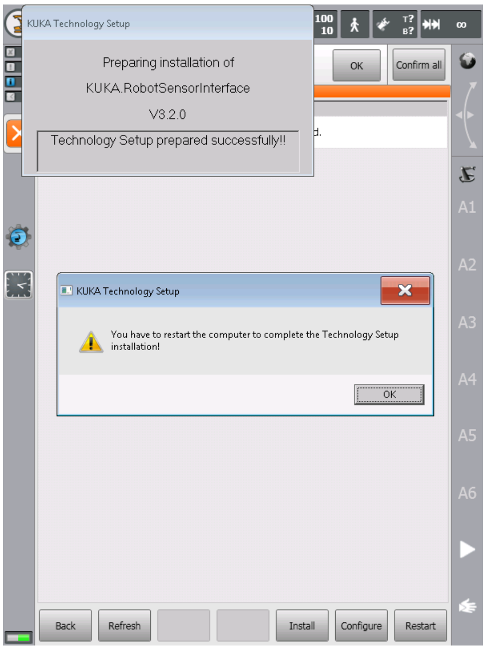
3. Click on an empty slot and click 'Path selection'



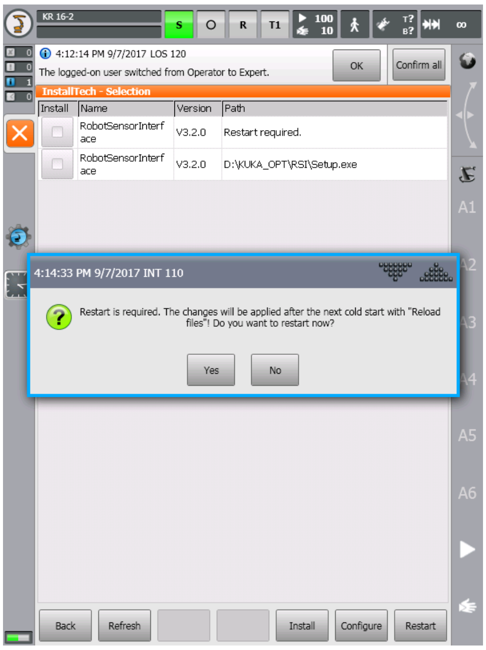
4. Browse for the installation folder of RSI, then click 'Save' twice



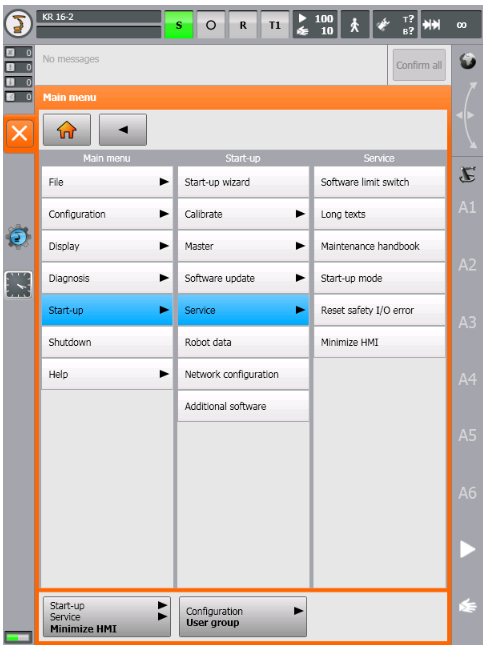
5. Mark the check box next to the RSI package name



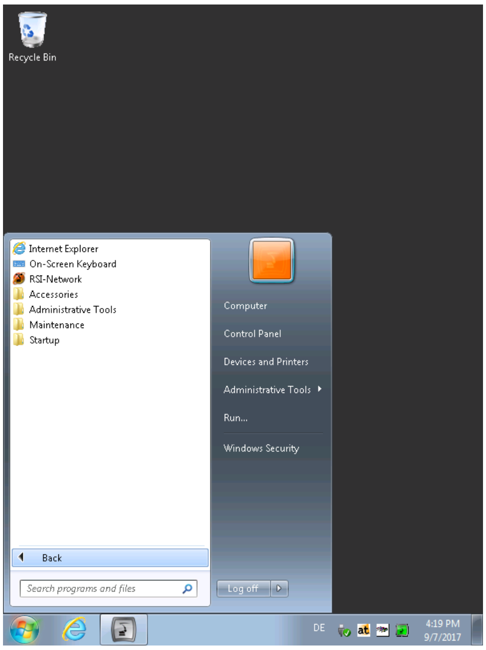
6. Wait for the installation, accept all prompts



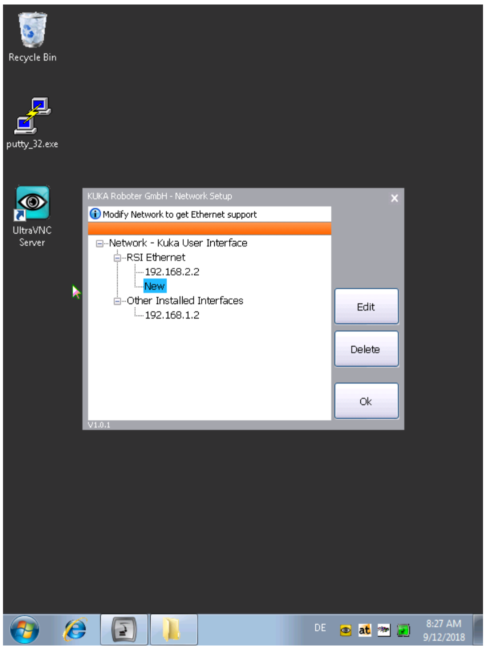
7. Click ‘Yes’ when asked to reboot the robot controller



8. After the reboot go to ‘Start-up’ > ‘Service’ > ‘Minimize HMI’



9. Click on the Start menu and open the ‘RSI-Network’ application



10. Click on the ‘New’ field under ‘RSI-Ethernet’ and click ‘Edit’. Enter an IP address with a different subnet that KLI

2.4.3 OnRobot KUKA Software Installation

Go to ‘Main Menu’>‘Configuration’>’User group’ and select ‘Expert’ mode. Enter your password, then go to ‘Start-up’>’Service’>’Minimize HMI’.

Plug the provided USB-drive into one of the control box’s USB ports.

Browse for the OnRobot KUKA Setup program and launch it. This program has multiple purposes: You can use it for the initial installation of the OnRobot KUKA package, but also as a network configuration tool.

On the welcome screen click next.

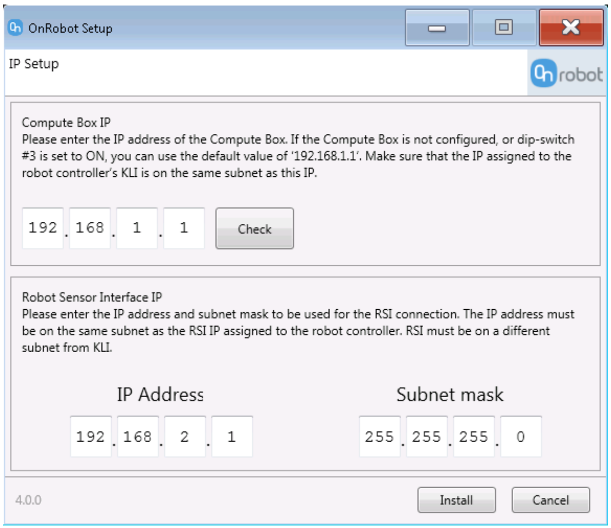
On the next window you will find three input fields. The first is for defining the Compute Box to be used with your robot. The second and third one is for defining the RSI connection.

First enter the IP address of the compute box you want to use with the robot. The default address is 192.168.1.1, use this if your Compute Box has not been configured yet or if it is set to fixed IP mode.

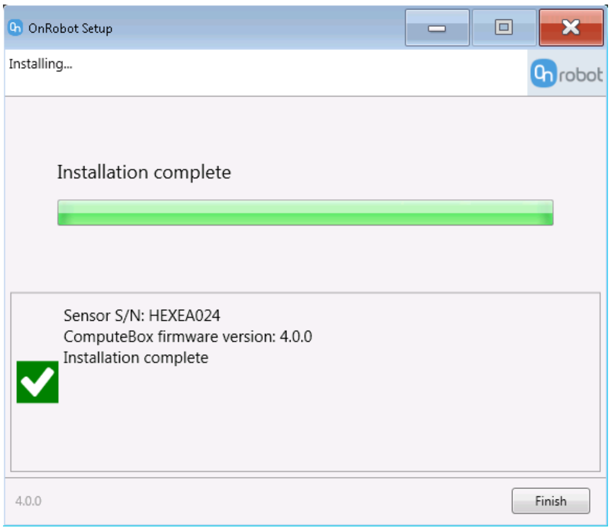
After entering the IP address click on ‘Check’. If the program successfully makes a connection to the Compute Box a green tick mark will appear along with the name of the sensor plugged into the box, and the version of the Compute Box software.

After successfully setting the Compute Box IP, continue by entering the IP and subnet mask for the RSI connection.

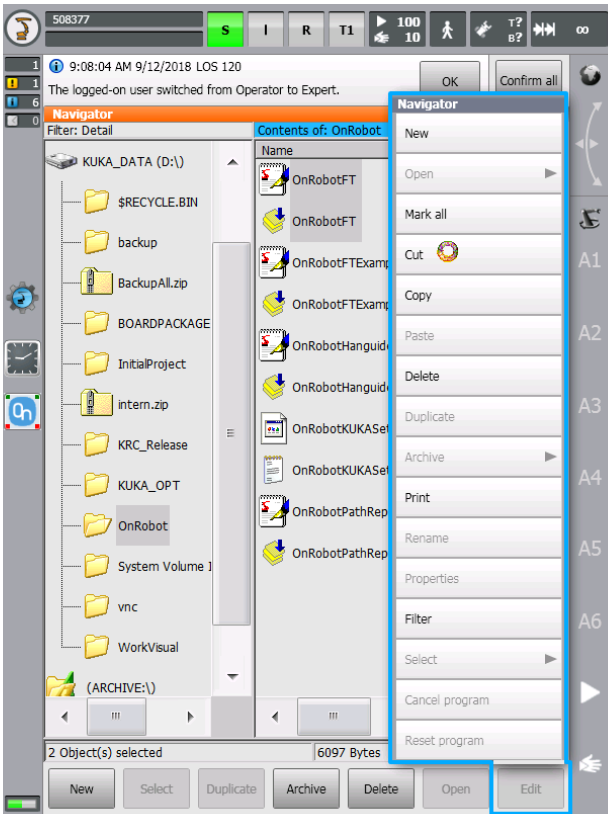
The IP you enter here must be on the same subnet as the one you defined during the RSI setup. (E.g.: if you set 192.168.173.1 for RSI on the robot controller set 192.168.173.X here. X can be any number between 2 and 255.) Make sure that you also use the same subnet mask as on the robot controller.



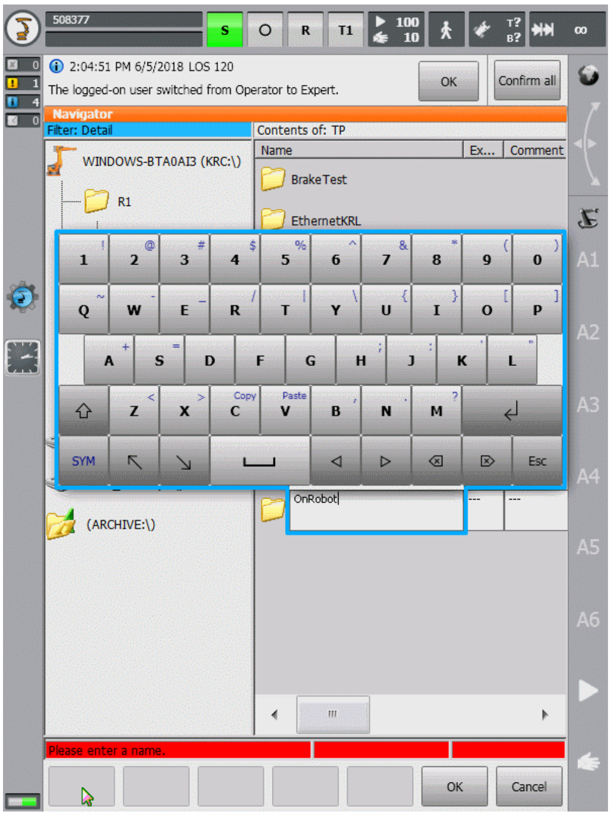
After filling in all the fields click on 'Install' to complete the installation/configuration. If the installation has been successful a green tick mark will appear. Installation failure can happen if there's a problem with the connection to the Compute Box or there's write protection on the robot controller's hard drive.



To complete the setup, go back to the Smart HMI and in the Navigator go to '`D:\OnRobot`'. Select '`OnRobotFT.src`' and '`OnRobotFT.dat`', then in the 'Edit' menu press copy.



Go to ‘KRC:\R1\TP’ and create a folder with the following name: `OnRobot`. Paste the two files into the new folder.



Restart the robot controller.

3 OnRobot Package Programming

3.1 Overview

3.1.1 KRL variables

`STRUC OR_AXEN BOOL X,Y,Z,A,B,C`

Structure used for enabling or disabling axes for force control.

`STRUC OR_FORCE_TORQUE_PARAM`

Structure used for defining the force control parameters. This structure has numerous fields that will be discussed in the force-torque control section.

3.1.2 KRL functions and subprograms

`OR_INIT()`

`OR_BIAS()`

`OR_HANDGUIDE()`

`OR_PATH_REPLAY()`

`OR_WAIT()`

`OR_FORCE_TORQUE_ON()`

`OR_FORCE_TORQUE_OFF()`

3.2 Initialization

3.2.1 OR_INIT()

This subprogram must be inserted into any code using OnRobot force control commands to initialize parameters for the proper behavior of all commands. It must be included only once and must be before the first OnRobot command.

3.3 Hand Guide

3.3.1 OR_HANDGUIDE()

This subprogram launches the sensor guided hand-guide on the robot. The program includes a BCO move to the actual position the program is launched at. **Do not touch the sensor or any attached tools upon starting the program.**

The argument of this subprogram is used for limiting the motion of the robot along or about certain axes. In the example below movement along the Z-axis is disabled along with rotations around the A- and B-axes.

OR_HANDGUIDE has a conservative speed limit on it, but

Example:

```
DECL OFAXEN ENABLED_AXES
ENABLED_AXES={X TRUE, Y TRUE, Z FALSE, A FALSE, B FALSE, C
TRUE}
OR_INIT()
OR_HANDGUIDE(ENABLED_AXES)
```

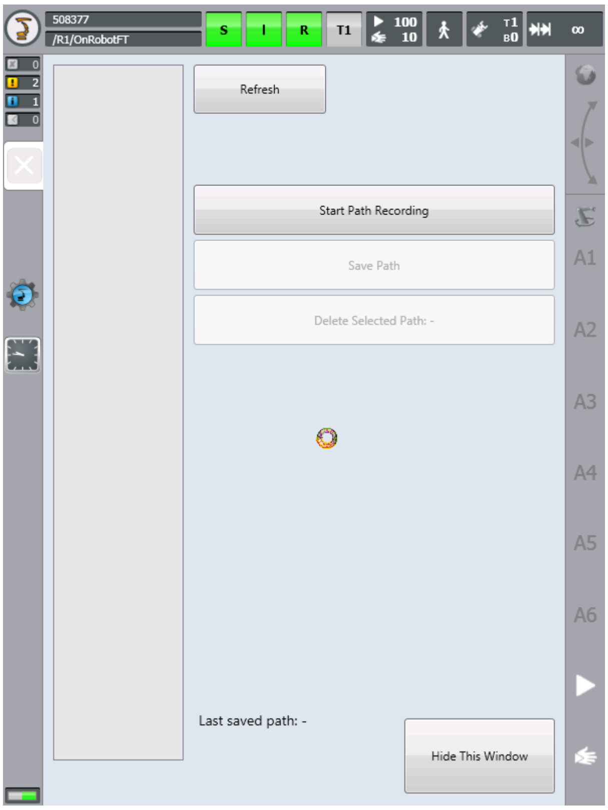
3.4 Path recording and replay

3.4.1 Recording a path

You can record any movement the robot does, be it a path created by manually hand guiding the robot or the shape of a surface during a force-controlled movement. In any case, the path recording must be initiated manually using the path recording GUI. The GUI can be summoned using the 'On' icon on the left side toolbar of the SmartHMI.

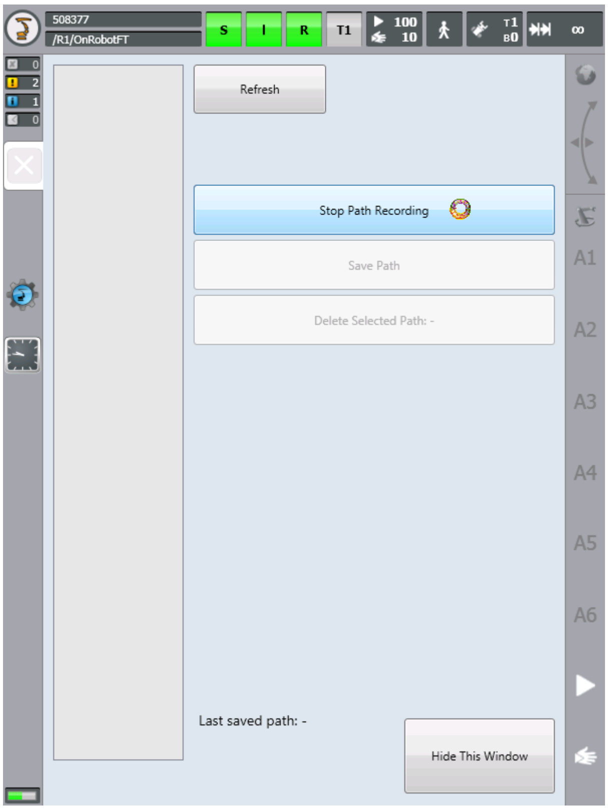
In order to record a hand guided path, the following steps should be followed:

1. Create a program (or use the provided example program) that has a OR_HANDGUIDE() command in it to launch hand guiding.
2. Select the program and start it. It is recommended that you use a Teach mode for this.
3. Move the robot into the position that you want to start the path recording from. You can use hand guiding for this, but since all recorded paths are considered as relative motions it is recommended to use explicit programmed positions as starting points. This makes replaying and path reusability easier.
4. When the robot is in hand guiding mode and in the correct initial position, select the  icon on the left toolbar to bring up the path recording GUI.
5. Press **Start Path Recording** to begin your recording session.

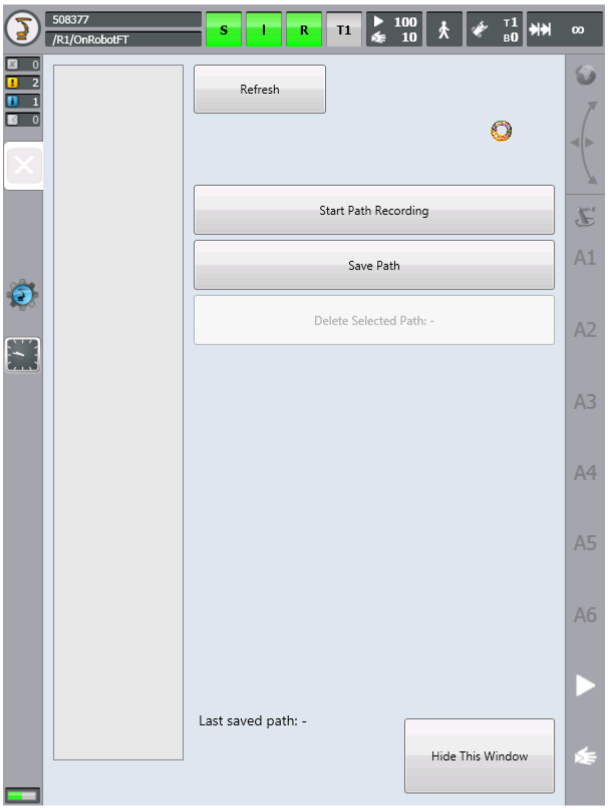


6. Move the robot along the path you wish to record.

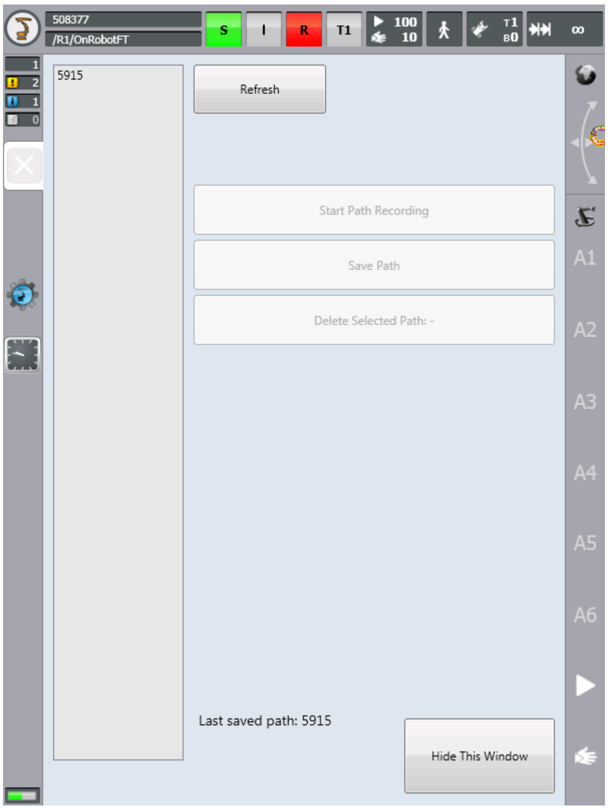
7. When you're done with the recording press **Stop Path Recording**.



8. If you're satisfied with the recorded path click on **Save Path**.



The new path will be added to the list on the left and its identifier will be displayed next to **Last saved path**. The path is now saved on the Compute Box.



This process can be used to record force-controlled movements too. This can greatly improve the accuracy and speed of the force control.

Saved paths can be exported via the Compute Box webpage and uploaded to a different Compute Box. Saved paths are interchangeable between robot makes (e.g. a path recorded on a KUKA robot can be replayed on any other robot supported by the Compute Box)

3.4.2 Replaying a path: OR_PATH_REPLAY()

This function can be used to replay paths stored on the Compute Box. The commands have three arguments:

`OR_PATH_REPLAY(SPEED:IN,ACCELERATION:IN,PATHID:IN)`

`SPEED`: The constant translational speed, in mm/s, used for replaying the path. This speed is global; thus, the robot will attempt to replay all movements at this speed. For this reason, rotations without translation should be avoided.

`ACCELERATION`: The acceleration and the deceleration, in mm/s^2, used for replaying the path. Use a lower number to achieve a softer acceleration at the beginning and the end of the path.

`PATHID`: The 4-number identifier of the path to be replayed.

<u>Return values</u>:

9: Path completed

-1: General error

-11: Specified path not found

-13: Specified path is empty

-14: Unable to open specified path file.

<u>Example:</u>

```
DECL INT retval
OR_INIT()
PTP {A1 0,A2 -90, A3 90, A4 0, A5 90, A6 0}
retval = OR_PATH_REPLAY(50, 50, 9159)
```

3.5 Force control

3.5.1 OR_BIAS()

Used for resetting the sensor values for a given load. Used for initial biasing of the sensor values during force control (except hand guiding) or biasing when the orientation of the sensor changes.

3.5.2 OR_FORCE_TORQUE_ON()

Activates the force control with predefined parameters. After the activation of the force control all movements will be superposed on the force control (either KUKA movement commands or path replay).

```
OR_FORCE_TORQUE_ON(PARAM:IN)
```

PARAM is the structure OR_FORCE_TORQUE_PARAM with the following fields:

FRAME_TYPE: The movement frame used for the force control. #BASE is the base coordinate system of the robot, fixed to the robot base. #TOOL is the frame fixed to the robot flange.

ENABLE: Defines the compliant axes with the OR_AXEN structure.

FRAME_MOD: Frame offset of the used coordinate system. Primary use is the rotation of the coordinate axes for force control along an oblique axis or plane.

P_GAIN: Proportional gain for the force controller. This is the most used parameter for basic force control. Determines how quickly the robot reacts to changes in force but can cause oscillations. These values should start small (1 for force, 0.1 for torque) and gradually increased to improve behavior.

I_GAIN: Integral gain of the force controller. Can be used to correct for persistent force errors (e.g. a sloped surface). Slows robot reactivity, increases overshooting.

D_GAIN: Derivative gain of the force controller. Can be used for damping controller induced oscillations. Slows robot reactivity, high value increases oscillations.

FT: Definition of the target force to be held along the axes defined by FRAME_TYPE and FRAME_MOD. Disabled axes will ignore this parameter.

F_SQR_TH: Force threshold for squared force sensitivity. Can be used as a soft force cutoff in low force cases (the lower the force, the less sensitive, reduces oscillations). **If used all GAIN values must be drastically reduced.**

T_SQR_TH: Torque threshold for squared torque sensitivity. Can be used as a soft torque cutoff in low torque cases (the lower the torque, the less sensitive, reduces oscillations). **If used all GAIN values must be drastically reduced.**

MAX_TRANS_SPEED: Maximum translational speed allowed by the force controller. [mm/s]

MAX_ROT_SPEED: Maximum angular velocity allowed by the force controller. [deg/s]

3.5.3 OR_FORCE_TORQUE_OFF()

This subprogram switches off the force control.

3.5.4 OR_WAIT()

Wait specified amount of time during force control.

```
OR_WAIT(TIMEOUT:IN)
```

TIMEOUT: Amount of time elapsed during the wait in milliseconds.

Return value: 7: The specified amount of time passed.

3.5.5 Example force control

This example shows the parametrization of a force control movement that is compliant along all three translational axes while holding 20N in tool-z direction. After activation the robot waits two seconds (e.g. robot moves into contact) then moves 200 mm in the X-direction.

```
DECL OR_AXEN enable
DECL OR_FORCE_TORQUE_PARAM param
DECL POS pgain, dgain, igain, framemod, force
DECL INT retval, tmp

OR_INIT()

PTP {A1 0,A2 -90, A3 90, A4 0, A5 90, A6 0}

OR_BIAS()
enable = {X TRUE, Y TRUE, Z TRUE, A FALSE, B FALSE, C
FALSE}
pgain = {X 1, Y 1, Z 1, A 0.1, B 0.1, C 0.1}
dgain = {X 0, Y 0, Z 0, A 0, B 0, C 0}
igain = {X 0, Y 0, Z 0, A 0, B 0, C 0}
framemod = {X 0, Y 0, Z 0, A 0, B 0, C 0}
force = {X 0, Y 0, Z 20, A 0, B 0, C 0}
param.FRAME_TYPE = #TOOL
param.ENABLE = enable
param.FRAME_MOD = framemod
```

```
param.P_GAIN = pgain
param.I_GAIN = igain
param.D_GAIN = dgain
param.FT = force
 param.F_SQR_TH = 0
 param.T_SQR_TH = 0
 param.MAX_TRANS_SPEED = 0
 param.MAX_ROT_SPEED = 0
 OR_FORCE_TORQUE_ON(param)

 ;WAIT 2 sec
 tmp = OR_WAIT(2000)

 ;KUKA MOVE
 PTP_REL {X 200}
 OR_FORCE_TORQUE_OFF()
```

4 Glossary of Terms

Term	Description
Compute Box	A unit provided by OnRobot along with the sensor. It performs the calculations needed to use the commands and applications implemented by OnRobot. It needs to be connected to the sensor and the robot controller.
OnRobot Data Visualization	Data visualization software created by OnRobot, to visualize the data provided by the sensor. Can be installed on Windows operating system.

5 List of Acronyms

Acronym	Expansion
DHCP	Dynamic Host Configuration Protocol
DIP	dual in-line package
F/T	Force/Torque
ID	Identifier
IP	Internet Protocol
IT	Information technology
MAC	media access control
PC	Personal Computer
RPY	Roll-Pitch-Yaw
SP	Starting Position
SW	software
TCP	Tool Center Point
UTP	unshielded twisted pair

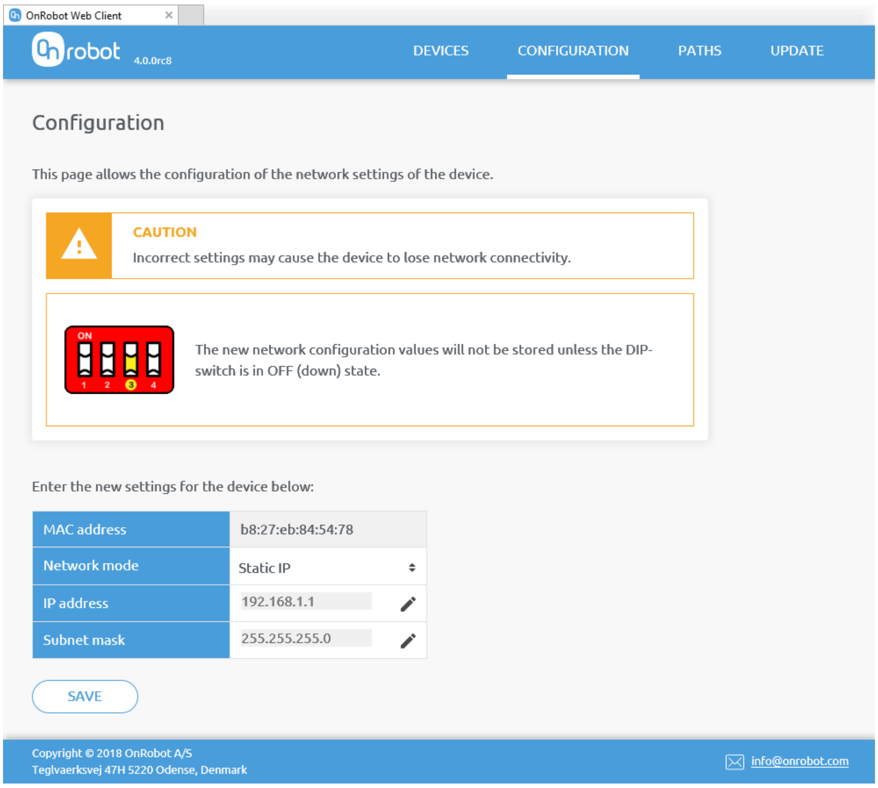
6 Appendix

6.1 Changing the IP of the Compute Box

To change the IP address of the sensor, connect your laptop or an external PC to the OnRobot Compute Box.

1. Make sure that the device is not powered. Connect the device and the computer with the provided Ethernet cable.
2. If your device is in the factory default settings, proceed to step 3. Otherwise, make sure to switch the DIP switch 3 to the ON position (up) and the DIP switch 4 to the OFF position (down).

3. Power the device from the provided power supply and wait 30 seconds for the device to boot up.
4. Open a web browser (Internet Explorer is recommended) and navigate to **http://192.168.1.1**. The welcome screen is displayed.
5. Click on **Configuration** in the top-side menu. The following screen is displayed:



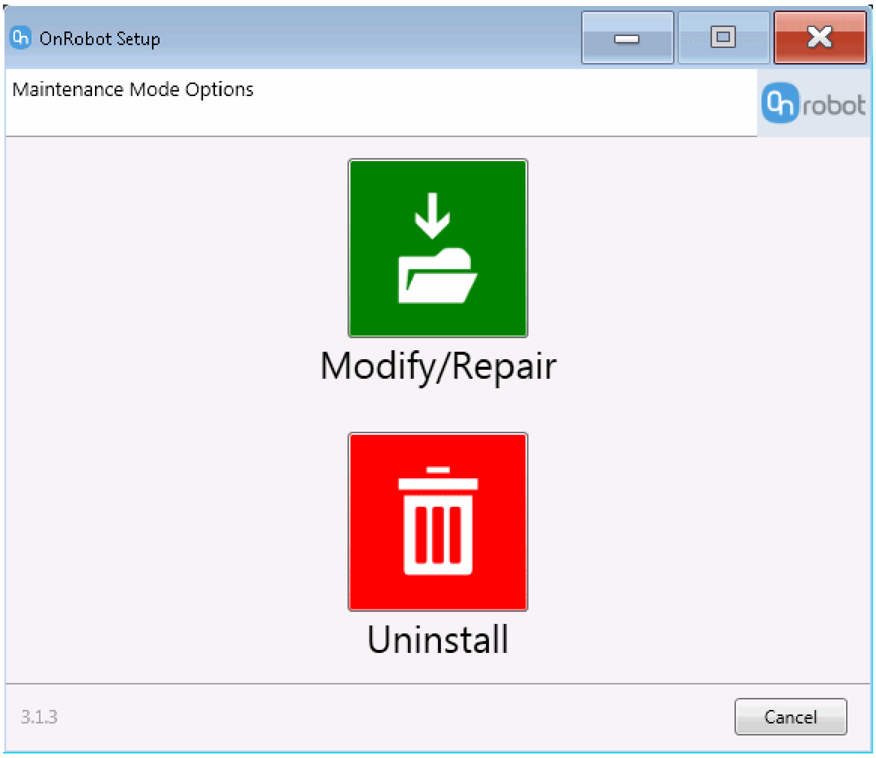
6. Select the **Static IP** option from the **Network mode** drop down menu.
7. Edit the IP Address.
8. Set DIP switch 3 to off position.

9. Click the **Save** button
10. Open a web browser (Internet Explorer is recommended) and navigate to the IP Address set in step 7.

6.2 Software Uninstallation

The following steps will uninstall the OnRobot package from your robot controller:

1. Enter 'Expert' mode by going to the Main Menu then 'Configuration'>'User group'.
2. Minimize the user interface with 'Start-up'>'Service'>'Minimize HMI'.
3. Open the file explorer and go to 'D:\OnRobot'.
4. Launch the OnRobot Setup executable file.
5. Click on 'Uninstall' and accept the prompts.



6. Restart the robot controller.

6.3 Editions

Edition	Comment
Edition 2	Document restructured. Glossary of Terms added. List of Acronyms added. Appendix added. Target audience added. Intended use added. Copyright, Trademark, contact information, original language information added.
Edition 3	Editorial changes.
Edition 4	Editorial changes.
Edition 5	Editorial changes.
Edition 6	Editorial changes.